Assessing Ecosystem Function Using a Landscape-scale Approach

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Abstract
The Washington state Department of Ecology is currently developing guidance to assist local governments in the application of landscape principles to planning and regulatory activities. This includes an approach for assessing ecosystem function that helps focus land-use planning on critical regional problems. This landscape approach was applied in the Drayton Harbor watershed just south of Blaine, Washington, which is experiencing regional water quality problems in freshwater and marine habitats. Through analysis of several data layers (land use, surficial geology, soils, water quality data, hydrography, and topography) a clear pattern of significant process alteration (surface and subsurface water and nutrient movement) was identified in the drainages with commercial agricultural activities. Within those drainages, measures to assist in the restoration of these processes were developed. This included the restoration of "strategically located" historic riverine wetlands in low gradient farmlands. The restoration is predicted to increase residence time with a corresponding improvement in water quality. The approach also allows development of appropriate zoning and use regulations that will ensure the long term protection of landscape scale processes and aquatic habitat within the Drayton Harbor watershed.

Introduction
Assessing ecosystem function using a landscape-scale approach helps focus land-use planning on critical regional problems thereby minimizing the cost and increasing the effectiveness of restoration. A landscape approach can provide a comprehensive method of assessing whether ecosystem processes have been altered; identifying the mechanism and geographic location of alteration; and determining viable restoration opportunities. Though this paper identifies wetland restoration as a means for addressing process changes related to regional water quality problems, the approach presented can be applied to a wide range of aquatic ecosystems and regional environmental problems involving movement of the water through the landscape.

An effective landscape analysis does not require exhaustive collection of new data, development of complex models to predict cumulative impacts, or lengthy analysis involving multiple development scenarios. Through use of existing data and land-use information and the application of some basic landscape principles, a comprehensive framework for protecting natural resources can be attained.

For the purpose of assisting regional planning efforts, the Department of Ecology applied landscape principles to two degraded sub-basins draining into Drayton Harbor. Dakota and California Creek are located in Northern Whatcom County, just south of the Canadian border (see Figure 1). These two sub-basins encompass the majority of sections within Township 40 North, Ranges 1 and 2 East. This area is presently rural but is on the verge of developing into a suburban community. Water quality problems are present in both sub-basins and in the Drayton Harbor estuarine area, which has resulted in the closing of shell fish beds since 1999.

This focused watershed analysis outlines the framework for developing solutions to mitigate for cumulative water quality impacts within the Drayton Harbor watershed by: (1) identifying changes to ecosystem processes (movement of water, sediment, nutrients, and energy); (2) using indicators to understand the link between land use and changes to these processes; and (3) identifying specific measures to restore some of these changes.

The landscape approach employed by DOE involves six steps:

1. Determine water flow patterns.
2. Validate if water flow processes have been altered.
3. Determine where water flow process have been altered.
4. Determine what regional problems have developed from process alteration.
5. Identify mechanisms to restore processes at a site level.
6. Identify and evaluate potential restoration sites based on process alteration maps.

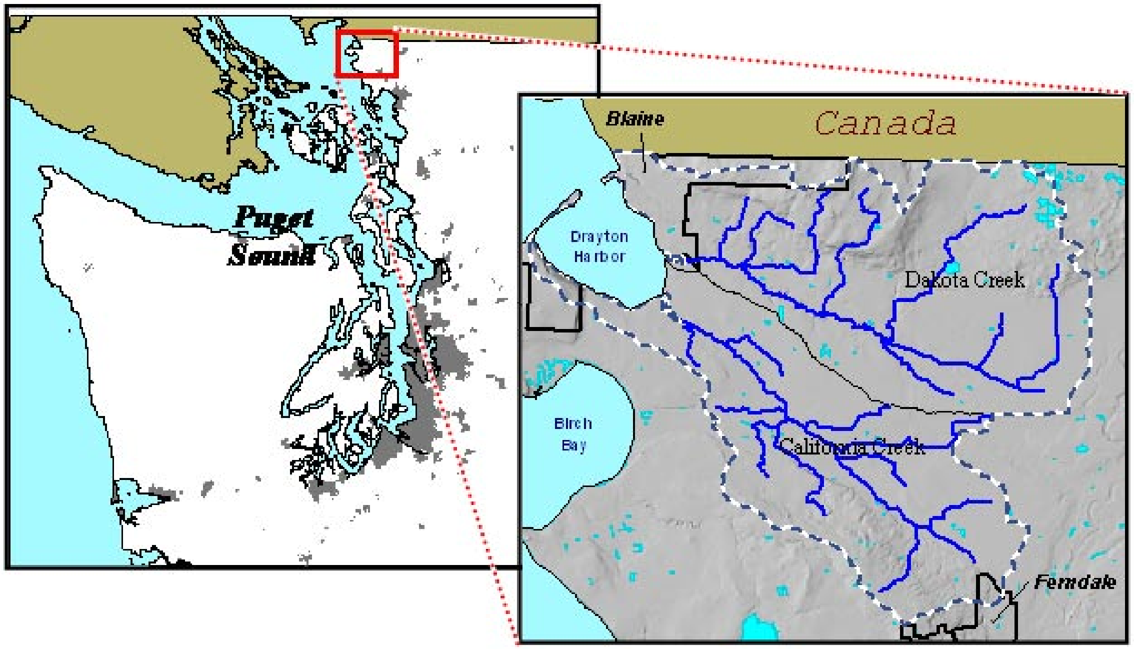

Figure 1. Location of Drayton Harbor Watershed.

Several data layers are required in order to apply the approach, including: soils; surficial geology, topography, and water network (i.e. streams, rivers, wetlands, lakes).

This landscape approach is based, in part, on the restoration strategy suggested by Beechie and Bolton (1999) which concentrates on diagnosing disruptions to processes instead of habitat conditions at a site specific scale. Mitsch (2001) also describes this type of approach as "ecotechnology— the use of natural ecosystems to solve environmental problems." Additionally, this landscape approach is based on the understanding of the "process, structure and function" hierarchy. This hierarchy and the thresholds at which alteration to land cover types negatively affects processes, structure and function is discussed below.

Watershed Process, Structure, and Function

There is an emerging body of research demonstrating that the biological, physical, and chemical characteristics (structure and function) of aquatic systems including rivers, streams, and wetlands are determined by the interaction of larger scale watershed processes (Beechie and Bolton 1999, Kaufman et al. 1997).

Ecological processes create and maintain the physical, chemical and biological attributes of a site (Gersib and others 1999) including the movement of water (surface and subsurface), sediment, nutrients, large woody debris, and energy (Naiman et al. 1992). The interactions of these processes with climate and geomorphology determine the structure (e.g., substrate, plant species) which in turn influences the type and performance of functions (e.g., water quality improvement, flow attenuation, food chain support) within those systems.

It is essential to analyze the restoration potential of an aquatic system within the context of watershed processes because they are the highest and most influential component of the hierarchy. Often restoration projects focus only on altering structure without considering the landscape processes which ultimately control the type of structure and function at a site scale. Thus, altering the structure has limited ecological effects because it does not address the core ecological problem at the landscape scale.

Wetlands provide one example of how processes affect habitat structure and function. Bedford (1996) argues that the "immense diversity of freshwater wetland plant communities and ecosystems" is the result of the interaction of water with the landscape (surface geology, soils, landform type). Human changes in the landscape, thus watershed processes, including groundwater and surface water flow, can then change the hydrologic inputs to wetlands. This change subsequently modifies wetland species composition and reduces species diversity (Wassen et al. 1989; Wassen and Barendregt 1992; Verhoeven et al. 1993). Research in King County demonstrated that hydrologic modifications throughout several watersheds resulted in reduced plant species diversity (Azous and Horner 2001).

Historically, assessment of wetlands has focused on functions despite the fact that the performance of most functions is affected by conditions many miles distant from the assessment site. This function-based approach has emphasized creating specific structure and habitat types within mitigation wetlands. This in turn has produced numerous mitigation wetlands with “artificially” created habitat structure (wetland geomorphology, sediment type, plant species) that may interrupt landscape scale processes (Beechie and Bolton 1999). Gwin et al. (1999) demonstrated that mitigation wetlands in the vicinity of Portland Oregon were “atypical” in that they did not represent the naturally occurring wetland types for the area.

Additionally, site-scale approaches in coastal areas often consider only freshwater impacts and fail to address the more significant cumulative impacts of process alteration on the adjoining larger marine ecosystem.

Therefore, in order to gain a basic understanding of the ecological significance of functions provided by wetlands, they must be evaluated within the context of the landscape in which they exist (Sutter 2001).

Description of Landscape-scale Processes

The primary watershed process that controls the delivery and routing of nutrients, sediment, large woody debris and energy is the delivery and routing of surface and subsurface water flows. Figure 2 depicts the different types of water delivery processes that are typically present in a landscape.

Water movement across and through the landscape, however, changes as vegetation is removed through forest practices, agricultural conversion, and/or urbanization (Dunne and Leopold 1978; Booth 1991; Euliss and Mushet 1996). Land-use changes affect runoff patterns within a basin and the hydroperiod of downstream aquatic systems, including wetlands (Booth 1991; Vought et al. 1995; Azous and Horner 2001).

With undisturbed conditions, surface runoff typically does not predominate in areas of high annual rainfall such as the Pacific Northwest. This is due to high rates of interception, infiltration, and evapotranspiration generated by the extensive “natural” vegetation cover (R. Ziemer 1998).

Surface runoff, however, predominates when infiltration and subsurface flow are reduced by:

- Removal of vegetation.
- Soil compaction (grazing).
- Reduction in size of soil particles (tilling).
- Reduction in microfaunal community.
- Drain tiles, ditching, road cuts, utility lines.
- Impervious materials.

Under these conditions, surface runoff essentially becomes saturated overland or “Hortonian” flow and the transit time of sediment and any other dissolved or adsorbed constituent is more rapid than if natural water delivery processes were in place (Ziemer 98).

For example, water flow processes are significantly altered in agricultural areas that have been tilled and ditched or suburban/urban areas that have impervious surfaces. Both situations result in overland flow during storm events and increased stormwater quantity and erosion/transport of sediment. Infiltration and subsurface flows are decreased and any sediment or debris, including wood, nutrients or other contaminants are rapidly moved downbasin to the main stream tributary.

In general, alteration of water flow processes results in a “shortening” of the path that water would follow on its route through a watershed which in turn decreases the “residence time” of ground and surface water within that watershed. As a result, there is a reduction in processes that: remove nutrients, pathogens and toxics (through filtering and cation exchange) in the soil column; filter out sediment from surface flows through vegetated buffers and wetlands; and reduce downstream flow peaks through interflow instead of saturated overland flow.

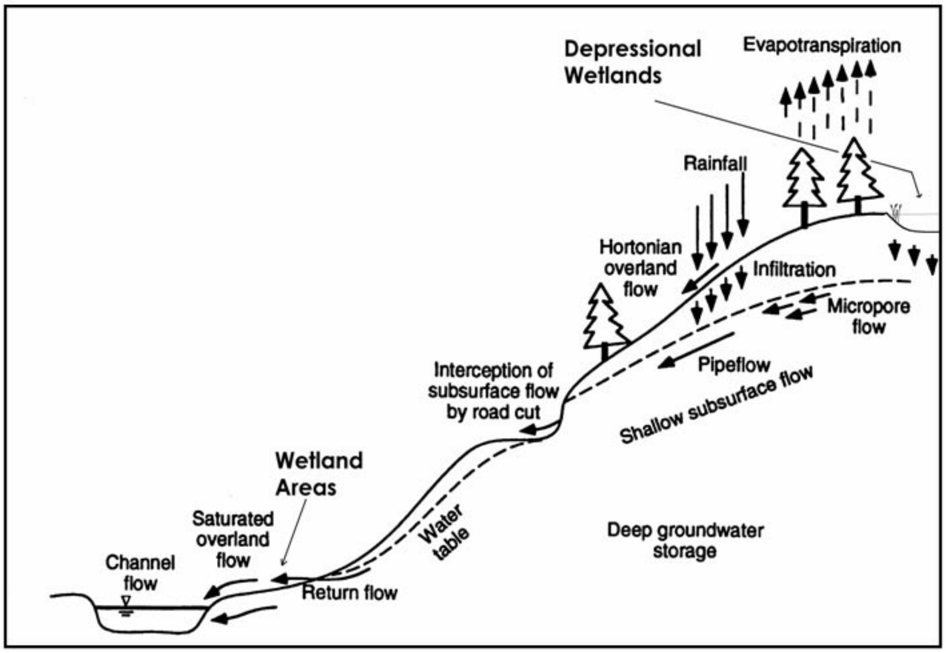

Figure 2. Water delivery processes. Source: R. Ziemer in River Ecology and Management 1998.

Additionally, these alterations result in increased rates, volumes, and durations of stormwater entering aquatic systems which cause: (Booth 1991; Azous and Horner 2001; Reinelt and Taylor 2001; Thom et al. 2001; Mallin et al, 2000):

- Increased erosion.
- Sediment movement and deposition.
- Burying of vegetation.
- Increased inundation.
- Water level fluctuations.
- Downcutting of natural channels (which can remove riparian vegetation from the floodplain).
- Changes in the seasonal extent and duration of saturation and inundation.
- Decreased water quality.
- Increased nutrient and bacterial contamination of fresh and salt water ecosystems.

Thresholds at Which Landscape Alteration Significantly Impact Aquatic Resources

Research throughout the country and here in the northwest indicates that the percent of impervious area and forested cover within a watershed govern the degree of process alteration and impacts to the structure and function of aquatic habitat. For impervious surfaces, research generally indicates that 10% or more impervious cover within a basin can result in significant impacts to habitat structure and function of freshwater aquatic ecosystems (PEW 2002). This threshold will vary depending on the different physical, chemical and biological characteristics and patterns of impervious surface.

For forested cover Booth et al (2002) have determined that natural hydrologic processes are maintained if 65% of a watershed is still forested.

Step 1— Identify Water Flow Processes and Patterns

By examining the soils, topography and surficial geology a cross section can be developed which provides a general depiction of the water flow patterns in the study area. An online tool developed by the Department of Ecology can assist in creating this cross section. (http://www.ecy.wa.gov/programs/sea/SMA/data/index.html)

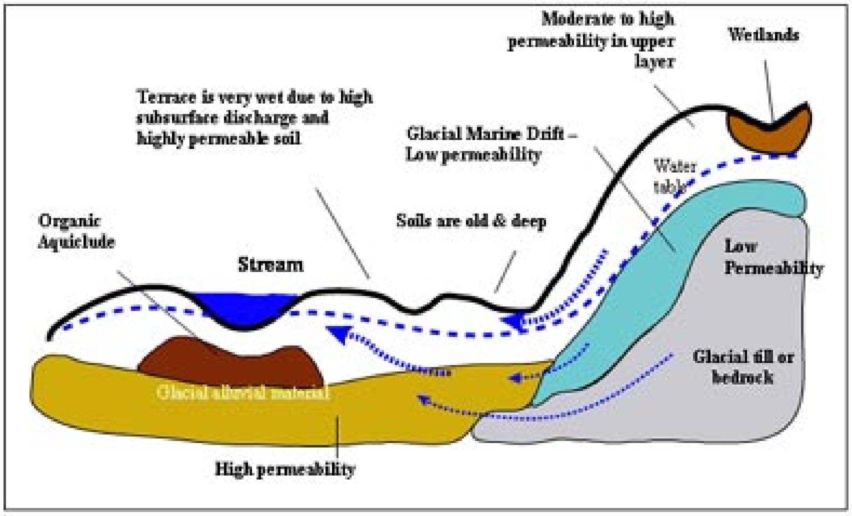

Figure 3. Water flow patterns and surficial geology for Dakota Creek sub-basins

The following cross section was developed for the Drayton Harbor area.

For the Dakota Creek sub-basin there is high surface and subsurface runoff from the adjacent slopes due to the presence of very impermeable marine drift formations. The terrace outwash deposits are relatively impermeable and serve as both areas of recharge and discharge. Discharge occurs at slope breaks, depressions and stream channels. These outwash terraces tend to be very wet during the early part of the growing season but due to higher permeability and transmissibility, the ground water table can drop rapidly in the early summer months.

Step 2—Validate If Water Flow Processes Have Been Altered

To validate local observations of alteration of water flow processes within the study area, an initial assessment of the conditions in the watershed was conducted using the following criteria (see landscape questionnaire available at Ecology website http://www.ecy.wa.gov/programs/sea/SMA/data/index.html):

- The contributing basin has more than 10% impermeable surface.
- Less than 65% of the watershed is in forested cover.
- The predominate land use or land cover is commercial agriculture (tilling).
- A network of ditches and/or roads across the landscape regularly intercepts and re-routes surface and subsurface flows.

In order to conduct this initial assessment, existing land cover data was obtained from the Whatcom County Planning. This was used to create a map of the major land uses within the two sub-basins (See Figure 4).

Most of the commercial farms engage in more intensive use of the land which can involve tilling, extensive tiling and ditching to remove excess water, and application of fertilizer including spraying of dairy waste. Non-commerical agriculture consists primarily of lower intensity “hobby farming” including raising livestock and horses and some small commercial farms.

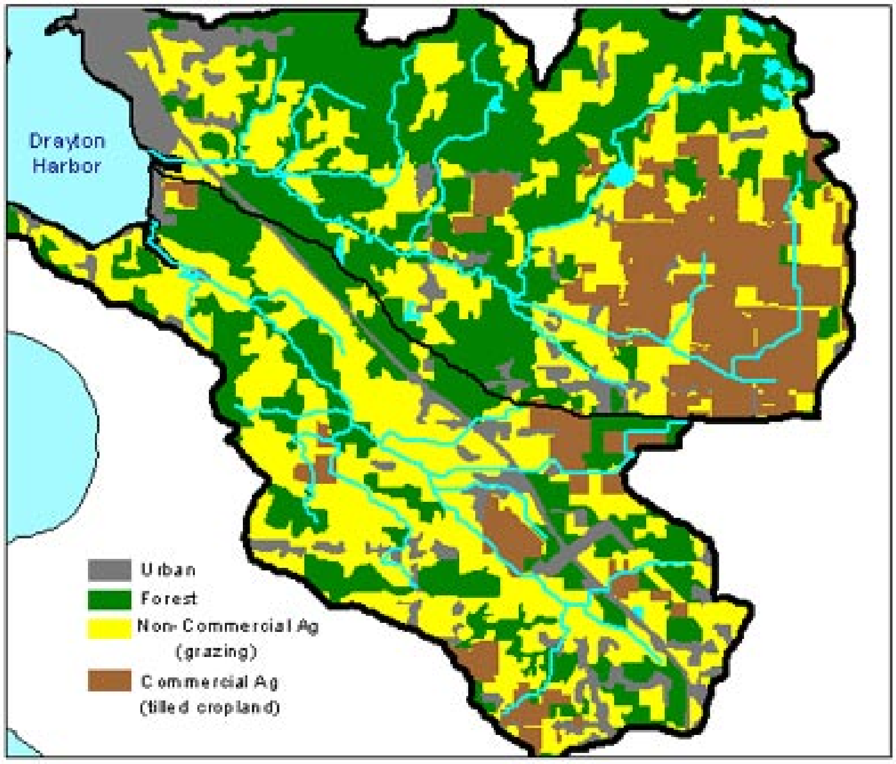

Figure 4. Existing land uses.

From this land cover a breakdown of the land uses within the study area was obtained (using Arc View land cover queries):

Table 1. Percent Land-use Cover and Acreage for Dakota and California Creek basins.

	Dakota Creek Basin	Acres	California Creek Basin	Acres
Forest	43%	8,140	32%	4,660
Agriculture (commercial and non-commercial)	49%	9,276	56%	8,099
Urban	6%	1,065	12%	1,752
Headwater wetlands and open water	2%	303		
Total Acres		18,785		14,511

Source: Department of Ecology Nooksack Data Base
Note: Agriculture includes rangelands and barren lands; California Basin does not include Hall Road sub-basin. Includes only those headwater wetlands judged to have minimal alteration; headwater wetlands which were judged to be moderately to significantly altered were not included.

To obtain a rough estimate of impervious cover a factor of 0.4 can be applied to the area of urban development (PEW 2002). For the California Creek Basin, impervious cover is estimated to be approximately 5% and for Dakota Creek the impervious cover is estimated to be approximately 2.4%. Because the majority of the impervious cover for the Dakota Creek Basin is presently concentrated in the lower portion of the watershed (i.e. City of Blaine), the impact upon watershed processes is not as significant as it would be if located in the upper watershed.

The initial assessment indicates that one of the four criteria, less than 65% forested cover is met for both the Dakota Creek and California Creek Basins. Therefore, landscape processes do appear to be altered for the study area sub-basins.

Step 3—Determine Where Water Flow Processes have Been Altered
By using NRCS Curve Numbers (TR55 - http://www.wcc.nrcs.usda.gov/hydro/hydro-tools-models-tr55.html) and information from the local Conservation District, the runoff levels for different types of landforms can be determined.

Table 2. Soil Hydrological Groups & Runoff Curve #'s for Dakota and California creeks.

Soils Types with Greatest Coverage	Hydro Group	Runoff Level Based on Hydro Group from NRCS TR 55		
		Residential, lot size 0.25 acre	Row Crops, straight row - good hydro cond.	Brush,Meadow, Woods Combo— good hydro cond
Dakota Creek Terrace Area— Glacial Outwash				
Edmunds Woodlyn (undrained)	D	87	89	73 to 79
Tromp	C	83	85	65 to 72
Laxton	C	83	85	65 to 72
Lynden	B	75	81	48 to 58
Everson	D	87	89	73 to 79
Average (not weighted based on area of soil type)		83	86	68
Dakota Creek Slope Area (northern portion of basin)— Glacial Marine Drift				
Whatcom	C	83	85	65 to 72
California Creek Terrace Area— Glacial Lacustrine				
Skipopa	D	87	89	73 to 79
Bellingham	C	83	85	65 to 72
Edmunds-Woodlyn	D	87	89	73 to 79
Tromp	C	83	85	65 to 72
Whatcom	C	83	85	65 to 72
Average (not weighted based on area of soil type)		85	87	72

Source for Hydro Group— NRCS Tech Release 55 and personal communication with Chuck Timlin, Whatcom Agriculture Service Center 1/7/03

The runoff curve numbers can then be applied to the land-use types presented on the land-use map and categories of runoff developed. Tilled agriculture, involving row crops, results primarily in surface flows; wooded, shrub areas results primarily in surface infiltration; and pasture areas (no commercial cropping or livestock operations) results in increased surface flows and less infiltration. These categories can then be displayed on a runoff map (Figure 5).

The runoff map (Figure 5) indicates that the area with the greatest degree of runoff corresponds to those areas shown on the land-use map consisting of commercial agriculture (tilling and dairy farms).

Using Water Quality Data
If existing water quality data is available, it can be used to determine if what is depicted on the land-use and runoff maps accurately reflects process alteration patterns. DOE used data collected in 2002 on conductivity, dissolved oxygen, and nitrates. The results are present in Figure 6.

The graphic labeled "total hot spots" shows the areas with the greatest number of water quality problems. These areas correspond to the same areas shown on the runoff map consisting primarily of commercial agricultural land-use activities. The sub-basin area with the greatest number of water quality indicators consisted almost entirely of dairy activity (and a large blueberry farm) and was located within the mid portion of the California Creek watershed.

Collecting water quality data can be time consuming and expensive and should only be used in a watershed analysis if existing sources of information do not give you a "clear picture" of process alteration patterns.

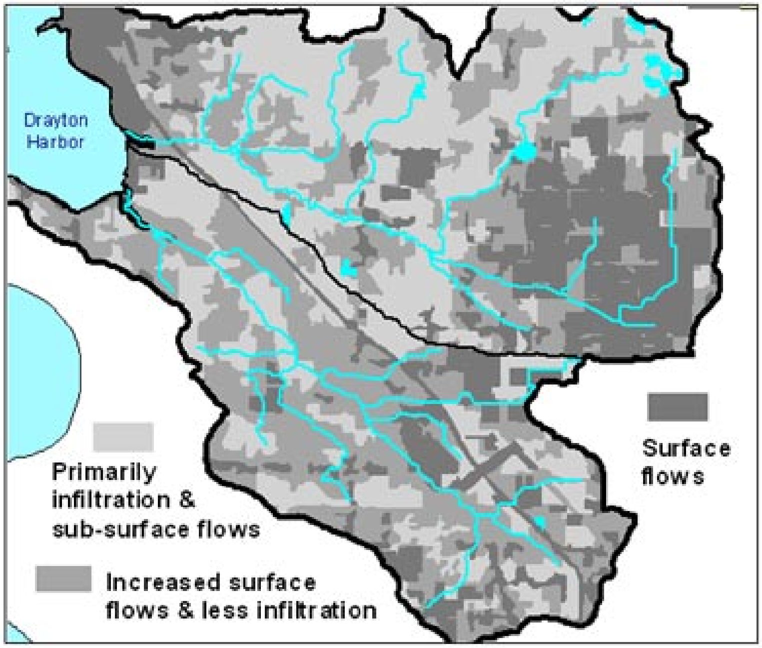

Figure 5. Map of runoff.

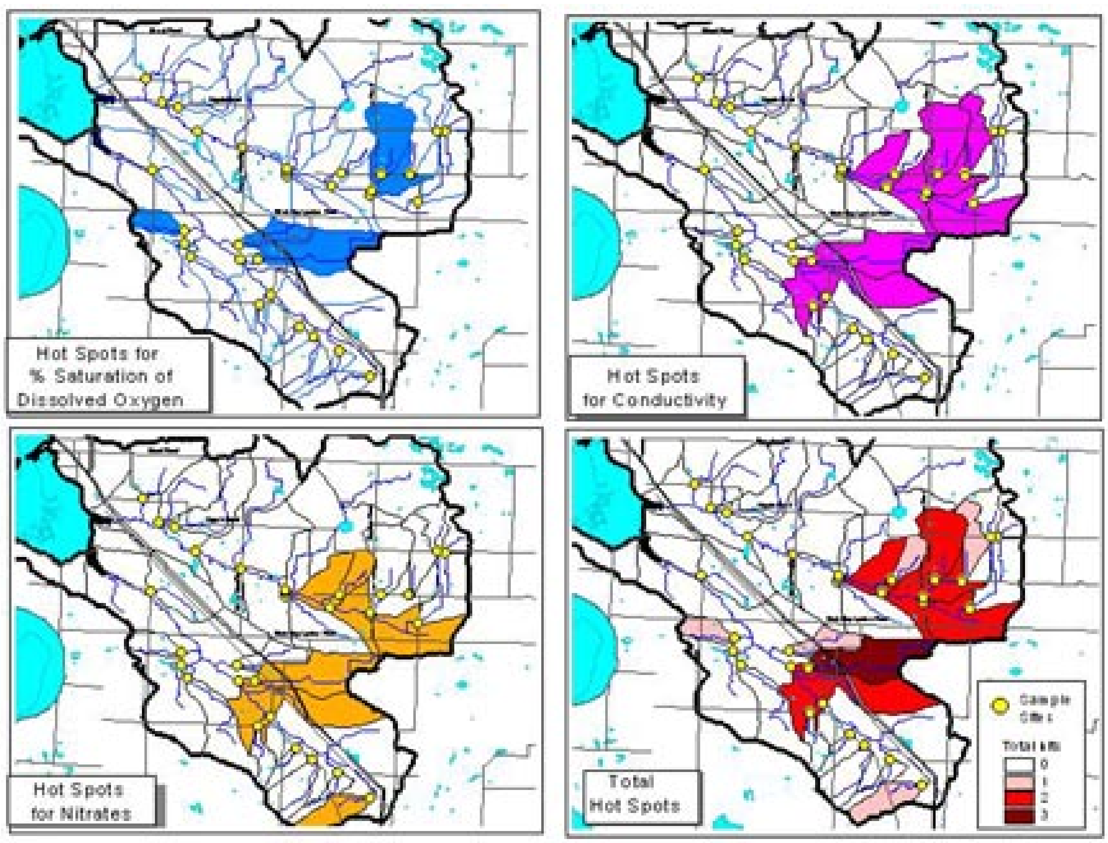

Figure 6. Results of analysis of water quality sampling data.

Therefore, the drainage areas that correspond to the areas depicted in the runoff maps and the water quality sampling maps should be considered as potential areas for focusing restoration planning efforts.

Step 4—Determine What Regional Problems Have Developed From Process Alteration
Determine what landscape-scale problems could be addressed by restoration activities (see landscape questionnaire at http://www.ecy.wa.gov/programs/sea/SMA/data/index.html). This first requires a summary of the type of process changes within the areas identified in Step 2. Both the Dakota and California Creek areas (e.g. commercial dairies and row crops) are dominated by surface flow due to a decrease in infiltration from commercial agricultural activities (water delivery process altered). This has also resulted in an increase in the quantity and velocity of stormwater flows downstream of these agricultural areas. In addition there is also increased erosion and transport of fine sediment and adsorbed/dissolved pollutants. Overall, the pathway for water movement has been shortened (lower utilization of groundwater path) and residence time of water is reduced through vegetation clearing, soil alteration, channelization of surface flows, and draining of wetlands.

Regional Problem in Drayton Harbor Area	Yes	No
Regional flooding?		√
Water quality?	√	
Downstream erosion?	√	
Loss of habitat connectivity?	√	
Loss of historic habitat?	√	

Based on these process changes, four landscape-scale problems were identified: water quality (fecal coliform and high nutrients in Drayton Harbor); habitat connectivity (large areas where riparian vegetation has been removed); elimination/reduction of historic wetland habitat; and downstream erosion (channel incision).

This study focused on the water quality problem, which is the most critical since it also involves impacts to a marine resource. The identified process changes (overland flow, reduced infiltration, limited aquatic buffers, and reduced wetland area -limited residence time) may be contributing to:

- Fecal coliform (FC)contamination which has closed shellfish beds in Drayton Harbor.
- Toxic Algal Blooms. (DOH Reported one in 11/01 for Drayton Harbor).
- Ulvoid Blooms. Puget Sound Action Team listed Drayton Harbor as area of "ongoing ecological concern." (Blooms of Ulvoids in Puget Sound, 10/2000).

This type of process alteration and corresponding impact upon coastal resources has been noted by other researchers. In his work along the North and South Carolina coastline, Mallin (2000a) noted that "rapid urbanization of these coastal areas is an important factor leading to shellfish bed closures." Mallin (2000b) found a strong correlation between average estuarine fecal coliform counts and the percent of developed land in a watershed and an even stronger correlation between average FC counts and the percent of impervious cover in the watershed. Mallin (2000b) concludes that coastal rivers are particularly susceptible to upstream land-use practices, and states that "poor sediment or nutrient retention practices, increasing development, and livestock farming have increased the potential for major effects on the benthic communities when storms and associated flooding occur."

Because areas that have a high level of clays are know to bind with potential pollutants, erosion and sedimentation in these areas can affect coastal water quality; sandier soils are less reactive and tend to not bind as many pollutants (Mallin 2000a).

Step 5—Identify Mechanisms to Restore Processes at a Site and Landscape Level
The two mechanisms for restoring water quality processes (delivery and routing of nutrients) include: (1) physical/chemical (adsorption of nutrients and heavy metals to sediment, physical removal of sediment by filtration from vegetation, and physical removal of sediment by ponding or "residence time;" and (2) biological (nitrogen removed through bacterial action, and fecal coliform removed by predatory bacteria and protozoans).

Both mechanisms are most efficient with increasing: residence time; vegetation density; and width of vegetated buffers. These mechanisms can occur in upland "buffer" areas next to streams, wetlands and estuaries in Drayton Harbor (e.g. riparian zones filter sediment which has adsorbed nutrients and other pollutants) or within aquatic areas, including floodplain wetlands (e.g. nitrogen removal and fecal coliform removal) and streams.

Furthermore, the biological mechanism for removing nitrogen from groundwater is very effective when riparian areas have an aquiclude (impermeable layer) that causes shallow groundwater flow (Gold et al. 2001).

Therefore, the overall goal is to reduce surface flows, stormwater peaks and the resulting downstream erosion and transport of sediment and associated nutrients, bacteria and other toxics. The primary means to accomplish this is through the restoration of subsurface flows and slowing of surface flows, to the maximum extent feasible, by increasing infiltration. Methods to accomplish this at the landscape level include:

1. Decrease in channelization of surface flows.
2. Increase in forested and scrub-scrub areas (goal of 65% for each watershed).
3. Restoration of riparian flow through and depressional wetlands in low gradient reache.
4. Restoration of riparian buffers.

Woltemade indicates that efforts to reduce sediment, nitrogen, and phosphorus loading of surface waters have "focused on restoration of forested riparian buffer strips..." He goes on to state, however, that wetlands are capable of providing similar functions, but have been less widely applied." Jordan et al (1993) demonstrates that riparian forest with a shallow underlying aquiclude is very successful in removing nutrients from groundwater. The critical factor is that groundwater is forced to move laterally through the near surface layers of the riparian forest. To accomplish this, all drain tiles and associated drainage ditches must be removed. Research by Gold et al (2001) determined that riparian sites located on outwash and organic/alluvial deposits have "high potential for nitrate-enriched ground water to interact with biologically active zones" and for denitrification to occur. Both the Dakota Creek and California Creek floodplains have shallow aquicludes (organic soils and outwash deposits for Dakota Creek and lacustrine and glaciomarine drift deposits for California Creek).

Step 6—Apply Findings to Determine Type and Location of Restoration Opportunities

The process alteration criteria presented in step 2 were then applied to the sub-basins selected for restoration. This is done in order to ensure that watershed processes have been altered and restoration is appropriate for these sub-basins. Three of the four criteria were applied to these restoration sub-basins, including: less than 65% of the watershed in forested cover; the predominate land use or land cover is commercial agriculture (tilling); and a network of ditches and/or roads across the landscape regularly intercepts and re-routes surface and subsurface flows. This indicated that processes had a greater degree of alteration in the proposed restoration sub-basins relative to the overall study area.

The next question is where to locate the wetland restoration. Research indicates that wetland restoration located within the appropriate position in the landscape can result in significant improvements in water quality functions:

- Small strategically located upland wetlands along "drainage lines" intercepted 23% nitrogen and 38% phosphorous for basin from diffuse agricultural sources (Raisin 1996).
- Small wetlands in the upper watershed are more effective than large constructed wetlands in the lower watershed (Loucks 1989; Mitsch 1992).
- Hammer has suggested use of riparian or linear wetlands along streams as strategy to intercept nutrients (1992).

Therefore, the proposed restoration area should be located in the upper portion of the watershed, within an area that has an aquiclude and is conducive to establishment of a riparian wetland (i.e. that can intercept nutrients). In addition, the area should have a low gradient so that the water quality mechanisms can act at their highest efficiency.

Areas of potential restoration were identified that meet the selected restoration goals, by examining soils, surficial geology, topography and land cover changes. Increasing residence time, vegetation density, and seasonal flooding were selected as the restoration goals for the sub-basins with the greatest number of water quality hotspots. To achieve this, historic riparian areas with low gradients, potential natural hydrology and hydric soils at the downstream ends of these sub-basins were examined.

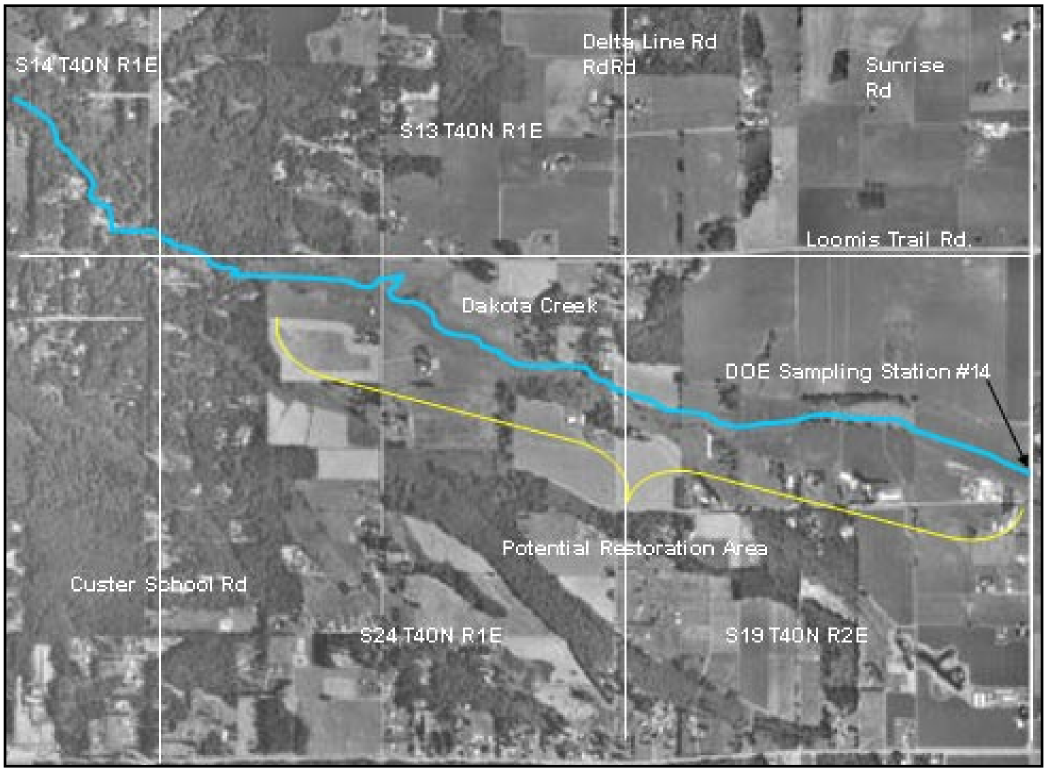

Figure 7 . Potential wetland restoration area for Dakota Creek. Downstream of this restoration area is primarily forested and therefore with less restoration potential.

The lower "downgradient" portion of the Dakota Creek "high priority" sub-basin (See Figure 7) shows potential for restoration of process, structure and function in a manner that would increase residence time and vegetation density and create seasonal wetlands (i.e. S24 T40N R1E and S19 T40N R2E). This sub-basin area is characterized by a low gradient floodplain (<2% gradient), organic soils and adjoining and underlying outwash deposits; upon restoration this area would be subject to overbank flooding and ponding of upper basin runoff. Based on the research by Gold et al (2001), riparian areas with organic hydric soils have the potential for a high denitrification rate.

Within the proposed restoration area the creek is presently channelized and its floodplain drained and grazed. Areas downstream of this area were also examined (S14, T40N, R1E) for restoration, but had a relatively intact forested stream corridor. Field observations indicated that the restoration goals set forth in this study were already being "substantially" met in these forested areas.

Restoration measures, including restoring overbank flooding, eliminating ditches/tiling and native scrub-shrub and forested vegetation would return natural processes with gradual development of structure and function occurring over a 5- to 10-year period. Figure 8 shows how the existing stream channel is dredged and tiling and grazing in the adjacent floodplain has resulted in elimination of floodplain riparian vegetation. This low gradient floodplain area is fairly broad and long and could, when restored with willows, cottonwoods, aspens, spirea and other riparian scrubs, result in considerable slowing of floodwaters, and increased filtering of sediment, nutrients and other pollutants.

For California Creek, the lower portion of the priority restoration area also has high potential for restoration of the "process-structure-function" relationship. This area is very similar to Dakota Creek in terms of topography and level of alteration. However, because the surficial geology is primarily glaciomarine drift (i.e. infiltration reduced) and the hydrologic soil group is "D and C," runoff can be potentially higher in this area. Therefore, to successfully restore water delivery processes for this area, it may be necessary to restore a larger area of wetlands in order to achieve a similar reduction of nutrients/bacteria relative to Dakota Creek.

Figure 8. View west of sampling station 14 along Dakota Creek of potential restoration area. Note broad floodplain extending out to line of trees. Ditching of stream and drainage of fields couple with grazing has reduced water quality and flood function of this area.

Size of Restoration Wetlands

The size of the wetland can be determined as follows:

- Wetland to Watershed Ratio of 1:25 to 1:30 results in 36% to 45% removal of nitrate-nitrogen in watershed (Woltemade 2000).
- This ratio also provides a retention time of 4 to 14 days (necessary for reducing fecal coliform populations).
- Based on this ratio approximately 140 to 168 acres of wetland restoration would be required for the selected Dakota Creek sub-basin.

The predicted water quality improvement performance of a wetland is dependent on the size of the contributing basin and the receiving wetland, the nutrient and hydrologic loading, and the soils and surficial geology of the basin and wetland restoration area. The ratio of wetland size to the contributing drainage area directly affects the retention time. Woltemade (2000) found that wetland-to-watershed ratio of 1:25 to 1:30 provided retention times of 4 to 14 days. This retention time is in the range necessary to significantly reduce FC populations in the Drayton Harbor watersheds. Woltemade also found that wetlands within the Embarras River watershed in Illinois with the above wetland to watershed ratio, removed 36% to 45% of the nitrate-nitrogen in the watershed (high flow events included). Mitsch et al (2001) estimates that restoration of 7% of wetland within the Illinois River watershed would remove 50% of the yearly nitrogen load.

Using the wetland to watershed ratio of 1:25 to 1:30 the following restoration acreages are estimated for the Dakota Creek and California Creek watersheds. These potential restoration sites and estimated restoration acreages are preliminary recommendations only. They have not been subject to either landowner or public input, which will be the next important step in considering the social and economic impacts and determining the feasibility of these potential restoration recommendations.

Table 3. Estimated Wetland Restoration Acreages for Dakota and California Creek Watersheds for Effective Nutrient/ Bacterial Removal. Based on 1:25 to 1:30 Wetland to Watershed Area Ratio.

Sub-basin Location	Sub-basin(s) Area	Estimated Area of Restored Wetland
Dakota Creek, Sub-basins above DOE Sample Stations D14,14a,15,16,17,18,19	4200 acres	140 to 168 acres
California Creek, Sub-basins above DOE sample station C4	373 acres	12 to 15 acres
California Creek, Sub-basins above DOE sample station C6	1112 acres	37 to 45 acres
California Creek, Sub-basins above DOE sample stations C5,7,8,9,10,13a,14	7574 acres	252 to 303 acres

Conclusions

Land-use managers can move away from the site specific, structure-based paradigm for natural resource recovery by using a landscape-scale approach similar to the steps presented in this paper. The site-specific, structure-based approach addresses local symptoms of habitat damage and fails to address the root cause of ecosystem degradation, which is usually due to process alteration at the landscape scale (Angermeier and Schlosser 1995; Montgomery and others 1995; Reeves and others 1995; Ebersole and others 1997). A landscape-scale approach allows land-use managers to incorporate ecological processes into their overall planning efforts that ensure the long-term protection of critical resources and functions important to society (e.g. maintaining water quality and reducing flooding and erosion).

The information derived from the landscape approach presented in this paper can be used not only to identify wetland restoration sites, but to develop zoning and land-use regulations that would protect and restore processes for an entire sub-basin. For example, the information revealed in steps one and three indicated that the glaciomarine drift slopes north and northeast of Dakota Creek have a very high rate of surface and subsurface runoff. Intense "traditional" suburban development in this area would have significant impacts on all downstream processes and would result in considerable degradation of water quality and habitat in both the freshwater and marine environments. Therefore, a land-use manager might consider zoning patterns that clusters development, providing "bands" or buffers of native vegetation (existing and restored) that intercepts and infiltrates surface flows.

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